■ ORIGINAL ARTICLE SPINE SURGERY AND RELATED RESEARCH

What Type of Orthosis is Optimal for Conservative Treatment of Lumbar Spondylolysis?: A Biomechanical Analysis

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Abstract:

Introduction: To analyze the extent to which various types of orthoses can restrict motion of the lumbar spine and provide basic evidence regarding the optimal orthosis for conservative treatment of lumbar spondylolysis (LS), particularly. Although several orthoses have been developed and applied for LS with better outcomes for bony healing, basic data regarding which is optimal are still lacking.

Methods: Ten healthy voluntary participants were included in this study. Lumbar spine range of motion (ROM) was analyzed using a three-dimensional motion capture system (NEXUS 2.2, Vicon Motion Systems Ltd., UK) under five conditions wearing no orthosis (NB) and four types of lumbar-sacral orthoses (LSO): custom-made hard LSO (HO), soft LSO supported by four aluminum stays and a custom-molded back cast-panel named “Return to Sports” braces (RS), custom-made soft LSO known as Damen type elasticity corset (DC), and off-the-shelf soft LSO.

Results: HO showed the highest restriction of motion in all directions than the others. Especially, ROM of rotation and side bending were reduced to 58.3% and 63.6% compared with NB, respectively. The other three LSOs showed significantly higher restriction in extension, rotation, and side bending than NB. In flexion and side bending, DC showed significantly higher restriction than NB.

Conclusions: HO showed high restriction in all directions. RS showed higher restriction in extension than NB and less restriction in flexion and side bending than other custom-made LSOs. DC was the only soft LSO showing higher restriction than NB in flexion.

Keywords:
orthosis, lumbar spondylolysis, stress fracture, conservative treatment

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Introduction

Low back pain (LBP) is frequently seen in adolescent athletes[1]. Lumbar spondylolysis (LS) particularly, which is considered to occur as a stress fracture[2-4], is a major cause of LBP in these individuals[5,6]. Repetitive motion of extension and/or rotation of the lumbar spine generates very high stress on the pars interarticularis and leads to stress fracture[7-9]. Therefore, in conservative treatment for bony healing, various lumbar sacral orthoses (LSOs) have been used to minimize lumbar motion for immobilization of the fracture site[10,11].

Several favorable results have been reported on bony healing following conservative treatment using the LSO when an early diagnosis was made[10-14]. Clinically, the custom-made hard LSO showed superior bony healing rates in the early and progressive stages than other soft orthoses, including the custom-made Damen type elasticity soft corset (DC). In addition, in patients with terminal stage LS, bracing is effective for pain-control by stabilization of the pars defect[15,16].

As mentioned above, although there have been many reports on clinical outcomes of bracing, basic data on the extent to which such orthoses affect restriction of lumbar motion is still lacking. Therefore, the purpose of this study was to show biomechanical data on the restriction of lumbar motion by various orthoses that had been conventionally used for conservative treatment and to provide the best option for conservative treatment of LS.

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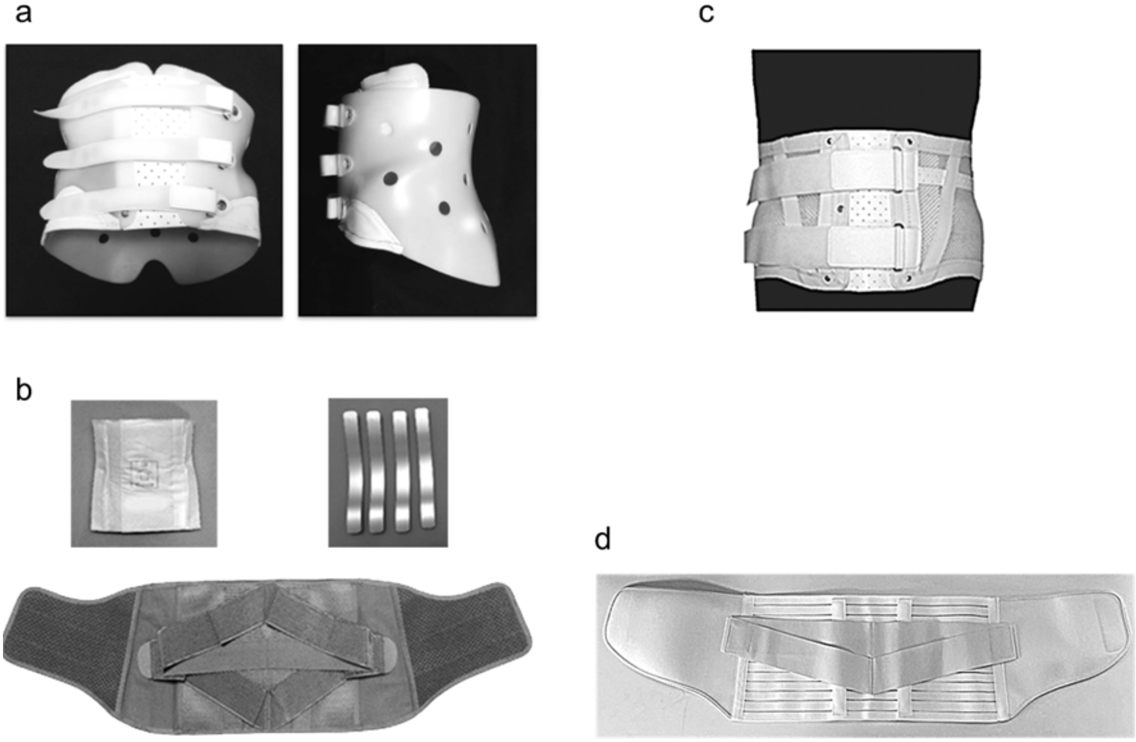

Figure 1. Four types of lumbar sacral orthoses (LSO) used in this study: (a) custom-made hard LSO (HO), (b) soft LSO supported by four aluminum stays and a custom-molded back panel named "Return to Sports" braces (RS) (Light-brace RS; ARCARE Co. Ltd., Tokyo, Japan), (c) custom-made soft LSO known as Damen type elasticity corset (DC), (d) off-the-shelf soft LSO (SO) (Max Belt R2; Nippon Sigmax Co. Ltd., Tokyo, Japan).

Materials and Methods

Study participants

Ten healthy adult volunteers (6 men, 4 women) participated in this study. Participants had a mean age of 27.0 (range: 22-32) years, mean height of 166.3 (range: 152-179) cm, mean weight of 60.6 (range: 52-74) kg, mean waist circumference of 72.5 (range: 63.0-78.3) cm, and a mean circumference of 1.5 cm below the anterior-superior iliac spine (ASIS) of 86.6 (range: 79.7-92.0) cm. No participants had any history of low back problems or spinal surgery. Informed consent was obtained from each participant, and the consent was written. This research has been approved by the IRB of the authors' affiliated institution.

Test materials

Four types of LSO were used in this study (Fig. 1): custom-made hard LSO (HO), soft LSO supported by four aluminum stays and a custom-molded back panel named "Return to Sports" braces (RS) (Light-brace RS; ARCARE Co. Ltd., Tokyo, Japan)[17], custom-made soft LSO known as DC, and off-the-shelf soft LSO (SO).

The HO was made of high molecular weight polyethylene and covered from 3 cm below the xiphoid process to 1.5 cm below the ASIS on the ventral aspect, and from 1.5 cm above its abdominal cranial end to 3 cm above the seating surface on the dorsal aspect. The RS was composed of an off-the-shelf soft orthosis with four aluminum stays and a custom-molded back cast-panel on the dorsal aspect. The area covered with the RS was defined by each size of the off-the-shelf soft orthosis. The DC was a custom-made orthosis using thermoforming nylon mesh and 10 thin stainless stays; it covered the same parts as the HO on the abdominal aspect and from 1.5 cm above its abdominal cranial end to 1.5 cm below its abdominal caudal end on the dorsal aspect. The SO was made of elastic fabric, two soft plastics stays, and four elastic belts (Max Belt R2, Nippon Sigmax Co. Ltd., Tokyo, Japan). The area covered with the SO was defined by a specified size.

Measurements and protocol

Three-dimensional (3-D) coordinates of 10 markers are measured by using a 3-D measuring instrument with 10 cameras (NEXUS 2.2, Vicon Motion Systems Ltd., UK). Its sampling rate was 100 Hz. Data were applied with low path filtering (fourth-order Butterworth low-pass filter with a cut off frequency of 10 Hz). Ten markers were set on the spinous process of the seventh cervical vertebra (C7), the center of the sternoclavicular joint, left acromion, right acromion, left ASIS, right ASIS, left posterior superior iliac spine (PSIS), right PSIS, pubic symphysis, and the tip of the coccyx. On wearing all types of LSO, markers on the PSIS were set on the surface of each LSO, and other markers were set on the clothes or skin. If the LSO covered the position of a marker, the LSO was partially cut off in order to

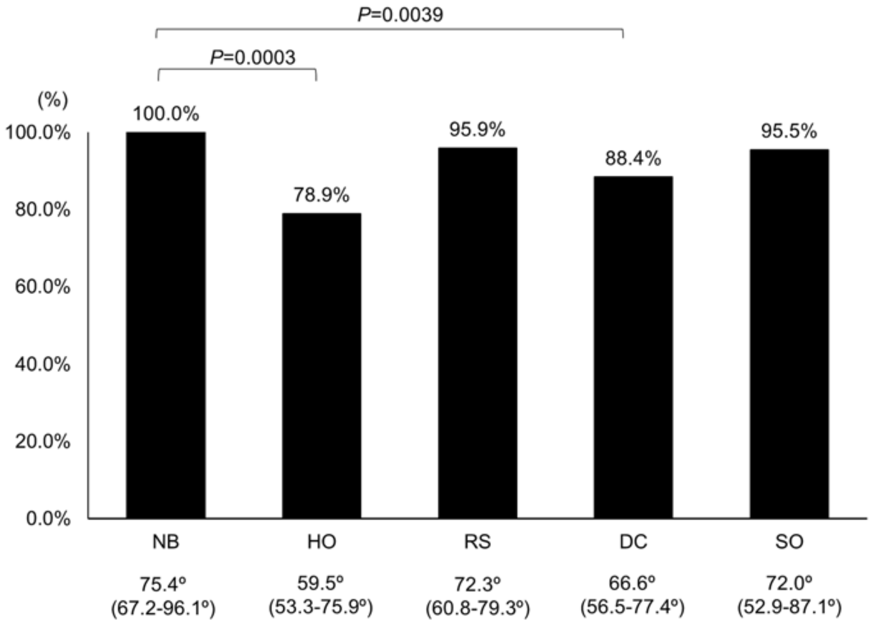

Figure 2. Range of motion (ROM) values of the spine with four types of LSO and NB in flexion. Data are expressed as percentages relative to NB. HO (*P*=0.0002) and DC (*P*=0.0038) showed significantly higher restriction than NB in flexion. Data are also expressed as median (interquartile range) under each bar.

place the marker. Coordinates of six markers were used for range of motion (ROM) calculation: C7, the center of the sternoclavicular joint, left ASIS, right ASIS, pubic symphysis, and the tip of the coccyx. Other markers were used adjunctively to check the framework model on the monitor.

Participants were analyzed under the five conditions of wearing the four types of orthosis and no bracing (NB) in the following motions: upright standing position, full flexion, full extension, full rotation, and full side bending, using a randomized block design. Each motion was attempted five times per participant. Undetectable data were excluded.

Calculation procedure

The angles of flexion and extension were calculated as the interior angle formed by two straight lines on the sagittal plane: a straight line joining C7 and the tip of the coccyx and a straight line joining a line perpendicular to the ground line. The angle of rotation was calculated as the interior angle formed by two straight lines on the horizontal plane: a straight line joining the center of the sternoclavicular joint and C7 and a straight line joining the pubic symphysis and the tip of the coccyx. The angle of side bending was calculated as the interior angle formed by two straight lines on the frontal plane: a straight line joining C7 and the tip of the coccyx and a straight line joining the left and right ASIS. Angles were calculated as an upright standing angle in the neutral position in each condition.

Statistical analysis

Measurements in full flexion, extension, rotation, and side bending were compared with the median of ROM in the five conditions: HO, RS, DC, SO, and NB. Measurements were analyzed using the Kruskal-Wallis test ($P < 0.05$) after the Shapiro-Wilk test ($P < 0.05$). Then the Steel-Dwass test for multiple comparisons ($P < 0.05$) was applied. All data are expressed as median (interquartile range). Statistical analysis was performed using SPSS 22.0.0.0 64-bit (IBM Corp., Armonk, NY) except for the Steel-Dwass test, which was done by using R2.8.1 software.

Results

ROM restriction in full flexion

Median values of the ROM in full flexion with HO, RS, DC, SO, and NB were 59.5° (53.3°-75.9°), 72.3° (60.8°-79.3°), 66.6° (56.5°-77.4°), 72.0° (52.9°-87.1°), and 75.4° (67.2°-96.1°), respectively. ROM with HO ($P = 0.0003$) and DC ($P = 0.0039$) were significantly less than that with NB. Each ROM of percentages relative to NB is shown in Fig. 2.

Based on these data, to restrict flexion of the lumbar spine, HO or DC should be prescribed.

ROM restriction in full extension

Median values of ROM in full extension with HO, RS, DC, SO, and NB were 22.6° (17.0°-27.9°), 24.4° (22.2°-26.6°), 27.4° (20.8°-31.2°), 26.9° (21.9°-30.0°), and 31.7° (27.4°-33.4°), respectively. ROM with HO ($P < 0.0001$), RS ($P < 0.0001$), DC ($P = 0.0133$), and SO ($P = 0.0218$) were significantly less than that with NB. Each ROM of percentages relative to NB is shown in Fig. 3.

Based on these data, to restrict the extension of the lumbar spine, all LSOs were significantly effective; however, HO showed the highest restriction (approximately 30%).

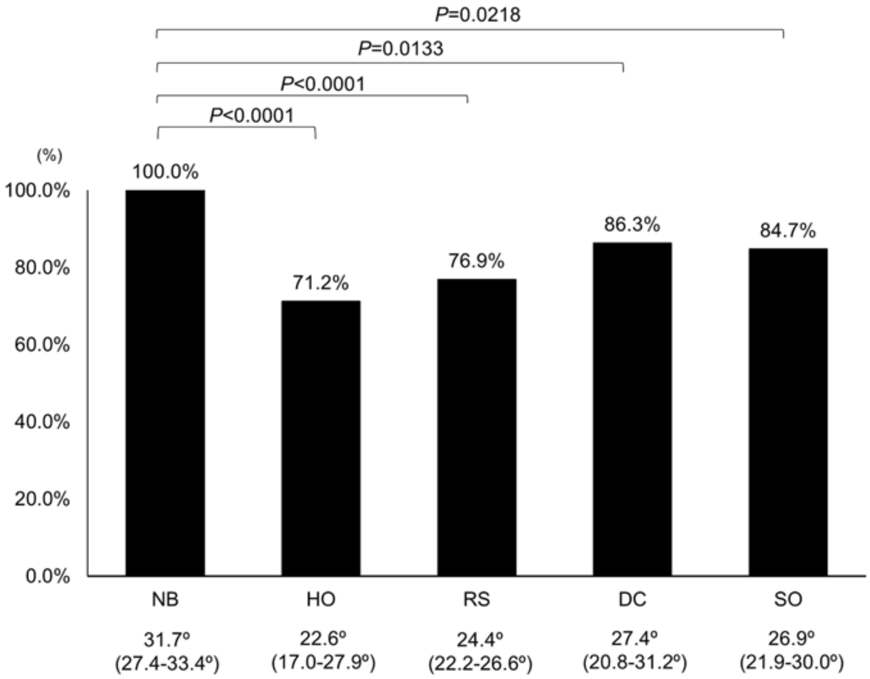

Figure 3. ROM values of the spine with four types of LSO and NB in extension. Data are expressed as percentages relative to NB. HO (*P*<0.0001), RS (*P*<0.0001), DC (*P*=0.0133), and SO (*P*=0.0218) showed significantly higher restriction than NB in extension. Data are expressed as median (interquartile range) under each bar.

ROM restriction in full rotation

Median values of ROM in full rotation with HO, RS, DC, SO, and NB were 23.1° (18.4°-26.3°), 28.0° (22.6°-33.7°), 28.4° (23.8°-36.1°), 29.3° (22.8°-37.0°), and 39.3° (35.4°-44.1°), respectively. ROM with HO was significantly less than ROM with RS (*P* = 0.0003), DC (*P* < 0.0001), SO (*P* < 0.0001), and NB (*P* < 0.0001). ROM with RS (*P* < 0.0001), DC (*P* < 0.0001), and SO (*P* < 0.0001) were significantly less than ROM with NB. Each ROM of percentages relative to NB is shown in Fig. 4.

Based on these data, to restrict rotation of the lumbar spine, all LSOs were significantly effective; however, HO showed the highest restriction (approximately 40%).

ROM restriction in full side bending

Median ROM values in full side bending with HO, RS, DC, SO, and NB were 15.2° (12.1°-18.7°), 20.3° (18.9°-22.8°), 18.9° (16.4°-20.4°), 20.1° (17.5°-23.4°), and 23.9° (22.0°-26.9°), respectively. ROM with HO was significantly less than ROM with RS (*P* < 0.0001), DC (*P* < 0.0001), SO (*P* < 0.0001), and NB (*P* < 0.0001). ROM with DC was significantly less than the ROM with RS (*P* = 0.0024) and NB (*P* < 0.0001). ROM with RS (*P* < 0.0001), and SO (*P* < 0.0001) were significantly less than ROM with NB. Each ROM of percentages relative to NB is shown in Fig. 5.

Based on these data, to restrict side bending of the lumbar spine, all LSOs were significantly effective. However, HO showed the highest restriction (approximately 35%).

Discussion

LS is regarded as a stress fracture of the pars interarticularis[2-4] and is caused by repetitive motions of extension and/or rotation of the lumbar spine[7-9]. Therefore, in conservative treatment for bony healing, LSO is required to minimize these lumbar motions for immobilization of the fracture site. Several recent studies reported an 80% to 100% bony healing rate with conservative treatment using LSO in the early stages of LS[10,11,13]. Specifically, HO showed superior bony healing rate in the early stage and progressive stages than DC or other types of soft LSO[10,13].

In the terminal stage of LS, pain-control to minimize the effects on the patient's daily life or athletic activities and/or to prevent subsequent spondylolisthesis are the main targets of conservative treatment[15,16]. In addition, for patients in whom bone union is achieved, prevention of recurrence of the stress fracture and/or conditioning before their return to athletic activities is important. Primarily, several types of soft LSO are also applied in these types of conservative treatment.

As mentioned above, several clinical outcomes have been reported, but basic data for choosing the optimal type of LSO for each condition has been limited due to the difficulty of validation of such studies. Using the Spinal Mouse® system (Idiag, Volketswil, Switzerland), Terai et al. showed ROM restriction in extension and flexion on wearing a soft LSO with a custom-molded back panel[17]. Similarly, Yamamoto et al. showed ROM restriction in extension, flexion, and side bending under three types of soft LSO also

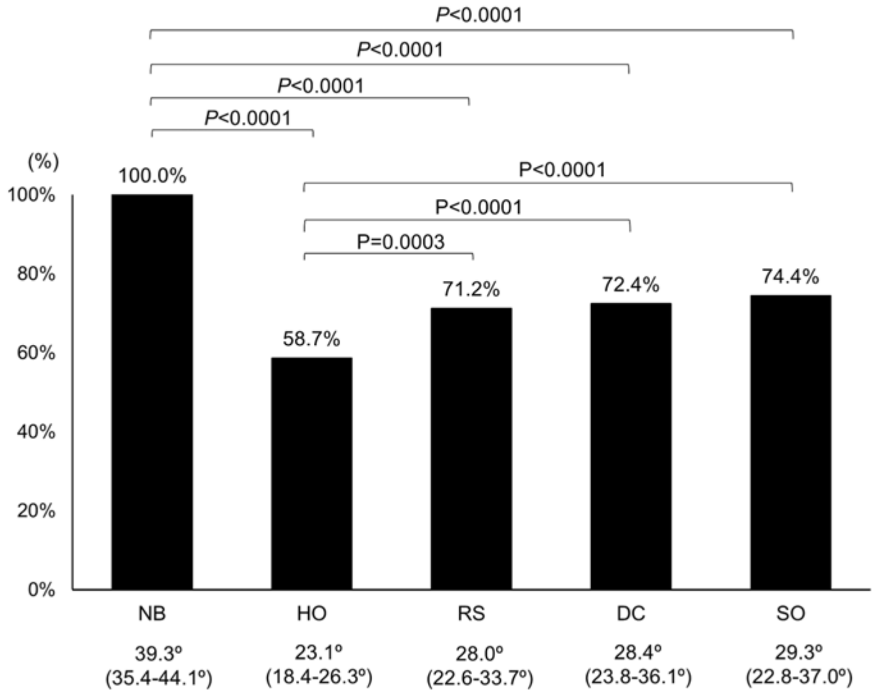

Figure 4. ROM values of the spine with four types of LSO and NB in rotation. Data are expressed as percentages relative to NB. HO showed significantly higher restriction than NB (*P*<0.0001) and other three types of LSO in rotation: RS (*P*=0.0003); DC (*P*<0.0001); and SO (*P*<0.0001). RS (*P*<0.0001), DC (*P*<0.0001) and SO (*P*<0.0001) showed significantly higher restriction than NB in rotation. Data are expressed as median (interquartile range) under each bar.

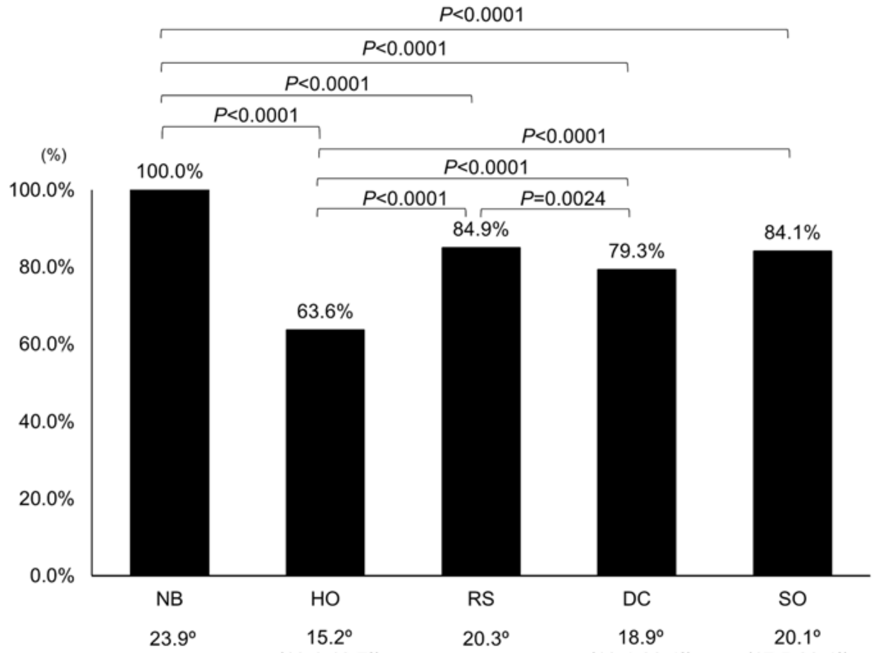

Figure 5. ROM values of the spine with four types of LSO and NB in side bending. Data are expressed as percentages relative to NB. HO showed significantly higher restriction than NB (*P*<0.0001), and the other three types of LSO in side bending: RS (*P*<0.0000), DC (*P*<0.0001), and SO (*P*<0.0001). RS showed significantly lower restriction than DC (*P*<0.0024) in side bending. RS (*P*<0.0001), DC (*P*<0.0001), and SO (*P*<0.0001) showed significantly higher restriction than NB in side bending. Data are expressed as median (interquartile range) under each bar.

with the Spinal Mouse® system[18]. Nakano et al. showed ROM restriction in extension and flexion under the general three types of LSO by radiographic analysis[19]. However, little is known about the extent to which ROM restriction of the lumbar spine is achieved by each LSO in each direction of motion, especially in rotation.

In this study, we presented biomechanical data on the restriction of lumbar motion by various LSO using the Vicon Motion System. HO showed the significantly highest restriction in rotation (58.8%) and side bending (63.6%) among the four types of LSO. Furthermore, HO showed higher restriction in flexion (78.9%) and extension (71.2%) than the other LSO, though the difference was not statistically significant. Based on clinical outcomes in past reports, Sairyo et al. showed bony union rate with DC in the early stage, progressive stage with high signal change (HSC) positive on the T2-weighted MR scan, progressive stage with HSC negative on T2-weighted MR scan, and terminal stage was 86.7%, 60.0%, 0.0%, and 0.0%, respectively[12]. Nakano et al. showed bony union rate with a soft LSO in the early stage, and the progressive stage was 85.7%, and 66.7%, respectively[19]. On the other hand, Sairyo et al. reported bony union rate with HO in the early stage, progressive stage with HSC positive on STIR MRI, progressive stage with HSC negative on STIR MRI, and terminal stage was 94%, 64%, 27%, and 0%, respectively[13]. HO appeared to obtain higher bony union rates than soft LSO, including DC. Especially, HO achieved 27% bony union rate in the progressive stage with HSC negative on MRI, although DC did not show any bony union. These results are considered to be affected largely by the kinds of the orthoses, which are consistent with the results of this study.

RS showed significant restriction in extension (77.0%), rotation (71.2%), and side bending (84.9%) than NB, but significantly less restriction in side bending than HO and DC. RS showed the highest restriction in extension (76.9%) among other soft LSO, though the difference was not statistically significant. In addition, RS showed no significant difference in ROM restriction with NB in flexion. To reduce stress on the pars interarticularis, restriction of extension and/or rotation of the lumbar spine is an important factor. In contrast, the lower ROM restriction in flexion and side bending suggests that it is easy to maintain the quality of performance of athletes. These characteristic ROM restrictions of RS may coincide with the idea about a suitable LSO for athletes who return to sports activities. However, RS showed less restriction in rotation at the same time. This is a risk for patients recovering from LS, especially those aiming to achieve bony union. Thus, caution must be exercised in this regard.

DC showed higher ROM restriction in all directions, especially flexion, than NB, which is considered relatively suitable for both bone union and treatment after bone union. Generally, HO has low compliance with wearing it due to the solidity, tightness, heat, humidity, and general discomfort. If patients cannot wear HO, DC can be an alternative plan.

SO showed significant restriction in extension, rotation, and side bending than NB. Each restriction was partially less than that of the other soft LSO. Nevertheless, SO would provide economy and convenience.

In this study, we measured the angular variations of the whole spine by using coordinates of markers on the body surface. Restriction of the L5/S mobility is a key for the conservative treatment of spondylolysis. However, current technology has a limitation to evaluate each intervertebral segmental mobility accurately under wearing the orthoses, and we evaluated the ROM restriction using the whole lumbar spine in this study. Further research will be required on this point.

Conclusion

HO showed high restriction in all directions and was suggested as the first choice in the conservative treatment for bone union in LS. RS showed higher restriction in extension than NB and less restriction in flexion and side bending than the other custom-made LSOs. RS was considered to be suitable for athletes who have recovered from LS, and need performance in their field with LSO. DC was the only soft LSO showing higher restriction than NB in flexion.

Conflicts of Interest: Y. Fujimoto is the representative director of Fujimoto Prosthesis and Orthosis Supply Co. Ltd. All other authors confirm that there are no conflicts of interest with people or organizations that could bias the nature of this report.

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Author Contributions: All authors contributed equally in the preparation of this manuscript.

Informed Consent: Informed consent was obtained from each participant, and the consent was written.

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